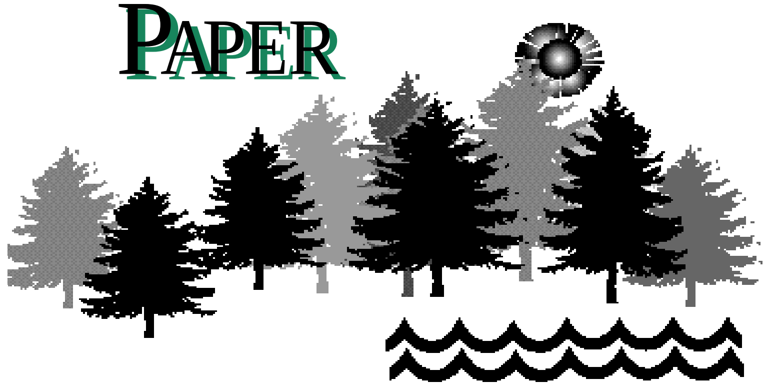
GREEN PAPER



Managing Solid and Hazardous Waste

by Joel S. Hirschhorn

An ironic indicator of economic progress is the amount of threatening solid and hazardous waste a country must cope with. As a result of increasing population, industrialization, urbanization, and economic wealth, larger amounts of waste are being generated in both industrialized and developing countries. Moreover, as the chemical nature of waste becomes more complex, waste becomes more of a threat to human health and the environment.

The traditional solution to increasing amounts of waste has been a regulatory one, focused not on waste generation but on how waste is managed, including acceptable, safe technologies such as secure landfills and incinerators. Although widely applied in the United States, such solutions have proven unsatisfactory.

One reason for this is technology. What governments accept as "safe enough" to manage waste, many environmentalists and concerned citizens find unacceptable because of air or water pollution. Also, although the amounts of pollution may seem small because control technologies are used, the increasing number of such pollution sources leads to cumulative releases of hazardous substances.

Another issue involves public policy. Relying on complex government regulations and their vigorous enforcement results in increasingly high costs for industry, consumers, and government itself, which inevitably lead to opposition to the regulatory system on the grounds that it stifles economic growth and may place industries at a competitive disadvantage in the global marketplace.

Because of the technology and policy issues, there has been only limited progress in solving solid and hazardous waste problems despite the existence of sophisticated systems for doing so. In developed countries, a kind of gridlock develops in which waste is viewed as the inevitable consequence of economic progress, and compromises are forced in order to balance environmental and economic objectives. Environmentally, the result is that problems are not solved effectively and they grow, increasing costs for future generations and testing the limits of pollution control technology.

In recent years, a newer, more promising solution to waste problems has emerged. Attention has shifted from costly end-of-the-pipe management of waste to a front-end, preventive strategy — waste reduction — that actually improves the economic infrastructure. The guiding principle behind waste reduction is that it makes more economic and environmental sense to reduce and eliminate waste where it is first created than to pay high costs for uncertain management and regulatory compliance after it is produced.

Yet waste reduction is no magic panacea that can be implemented immediately to make all solid and hazardous waste disappear. It must be viewed as the preferred option within a larger set of choices.

A WASTE HIERARCHY

The historically dominant method of dealing with solid and hazardous waste was fairly indiscriminate dumping of materials on land relatively near residential areas and industrial sites. As long as wastes were simple human and other organic matter that could naturally biodegrade, society did not have major problems.

In many places around the world, there was ample isolated land to dump high-volume wastes, such as from mining and farming activities, and even for larger amounts of urban waste. With low levels of industrialization, manufacturing wastes also were not dangerous. But with increasing industrialization and population growth, especially in urban settings, open dumping of wastes created more than a nuisance; it created a persistent threat to public health.

The situation became more complex after World War II, which precipitated the invention of new synthetic and often toxic materials and chemicals, including plastics, pesticides, and solvents and cleaning agents. Such chemicals in residential and industrial waste make a more sophisticated approach to waste disposal necessary.

Of course, in addition to open dumping, technical waste management methods were used, including open burning, simple waste burial, incineration in furnaces, and recycling. While the alternatives often seemed promising, inevitably it became clear that there was no single technological fix for all waste problems. For example, open burning and incineration, in their relatively early crude forms, produced considerable air pollution, including visible soot — particularly in growing cities. Crude forms of waste burial produced unstable and unusable areas

SOLID AND HAZARDOUS WASTE IN EGYPT

With a population of over 50 million and rising, as well as rapid industrialization and urbanization, Egypt has faced the full array of waste issues. In particular, greater Cairo, with a population approaching 10 million, presents a true solid waste challenge.

Until recent years, solid waste in Egypt often was indiscriminately discarded and dumped, and attempts at recycling were neither organized nor hygienic. But the situation is turning around as Egypt's government has recognized that its attempts to experience further industrial growth could be hampered by poorly managed waste. Too much waste at the end-of-the-pipe literally blocks new industries and new housing.

With World Bank assistance, the government has organized a number of solid waste studies and feasibility assessments as a first step in better understanding and controlling the problem. One important result has been basic information on solid waste generation, without which it is difficult to develop sound waste programs. For example, it was found that about 60 percent of Egyptian municipal solid waste (MSW) is from households, 15 percent is from businesses and institutions, 15 percent from street sweepings and gardens, and 10 percent from construction and demolition activities. About 60 percent of MSW is food wastes, 13 percent metals, 2.5 percent cloth, 2.5 percent glass, and 2 percent plastics; presumably, the remaining 20 percent is largely paper.

A major advance in Egypt was the 1986 introduction of sanitary or engineered landfills for solid waste disposal in the Cairo area. Also since the mid-1980s, about 80 incinerators have been introduced for MSW, but without energy recovery and rather small in capacity. However, the experience has not proved very successful because of high operating costs resulting from high fuel consumption (because of waste with high moisture and low heating value), high maintenance costs, and high labor costs. Thus, incineration will be pursued only for some industrial hazardous waste.

Composting looks promising as part of the waste solution, with about five facilities built in the 1980s. The high organic fraction of Egyptian MSW is an advantage. Poor soil quality in Egypt now requires high applications of fertilizers. Compost would have very high value for local agricultural uses and would reduce irrigation water and fertilizer needs.

Overall, Egypt illustrates the typical evolution of waste management. First, indiscriminate dumping is curtailed, and safer, more costly forms of land disposal are used. Then, attempts at waste treatment are used. However, the sharply rising costs of waste management face stiff opposition from industry and the public. The next step is to focus on waste reduction as the best solution. The uncertainty is whether Egypt and other countries will follow the historical movement up the hierarchy as the United States did — which could take several decades — or learn from costly U.S. experiences and jump more quickly to a national commitment to waste reduction.

as the waste decomposed and settled. Recycling had long been practiced for some especially valuable and easily retrieved waste materials such as scrapped automobiles, but in most countries recycling could not possibly handle the rapidly increasing diversity and amounts of solid waste. Nor could it be easily applied to industrial hazardous waste.

Gradually, developed countries began to realize that the methods used to cope with waste were becoming unsatisfactory and increasingly costly. The sheer volume of waste only compounded the problem. In the late 1970s and early 1980s, it became clear that a longer-term strategy was needed. The answer was the hierarchy of preferred options for solid and hazardous waste management. This hierarchy is relatively simple, and it makes policy, environmental, and economic sense. It has pointed the way to more promising and effective solutions and to a better mix of technical remedies.

The basic waste hierarchy now used nearly everywhere is, in descending order of preference:

- Waste prevention or reduction;
- Recycling (including composting);
- Waste treatment; and
- Land disposal.

This policy framework gives the clear message that land disposal is the least preferred waste management option, contrary to dominant historical practice. It also provides consistency with natural resource conservation; that is, waste is literally a waste of valuable resources, and waste is a source of resources to be recovered and recycled.

Although there is little debate about the waste hierarchy, its implementation remains a challenge. Various forms of land disposal still constitute the major way both solid and hazardous waste is managed worldwide, largely because it remains relatively low cost if its longer-term pollution and environmental cleanup costs are ignored. Nevertheless, larger amounts of waste are creating greater health and environmental problems for many countries.

Government policies in most industrialized nations and in some developing countries are geared to implement the waste hierarchy by providing incentives and assistance for prevention and recycling. Concurrently, governments are increasing the regulation and cost of incineration and land disposal. But in practice, moving from the bottom to the top of the hierarchy has proven very difficult. The following discussion is geared toward the waste hierarchy and presents various issues and solutions for its four levels.

WASTE REDUCTION

Although many different phrases are used — waste minimization, waste prevention, pollution prevention, source reduction, cleaner production, clean technology, green technology — one fundamental, universal principle is being applied: It is safer environmentally not to produce waste than to handle, transport, and manage it after it is generated.

In the United States and many other industrialized countries, waste reduction applied to both solid and hazardous waste has become a visible and important strategy that supports the goal of sustainable economic development by conserving and protecting natural and human resources.

One reason for stressing waste reduction is that there are limits to traditional pollution control and waste management methods, which are becoming unable to deliver cost effectively protection of health and environment as population and industrialization increase. In other words, there is a tyranny of numbers. The sources of pollution increase sharply, and even small amounts of toxic chemical releases that pass through pollution control equipment add up to unacceptable levels of pollution on a wider scale. Dilution is definitely not the solution when sources of waste and pollution expand everywhere at rapid rates.

A second reason for seeing waste reduction as the most promising of the waste management approaches is that it offers economic benefits rather than generating costs. As attention to solid and hazardous waste has increased, the costs of waste management for waste generators and for society as a whole have escalated sharply, with the use of more complicated and efficient pollution control equipment. In the United States, for example, stringent government requirements for waste landfills and incinerators have resulted in costs doubling over a relatively few years. Waste generators have discovered that they can reduce spending both on waste management and on raw materials by practicing pollution prevention.

But extensive regulatory systems do not exist in all countries. Thus, it is important to see waste reduction as one dimension of a technological innovation, modernization, and efficiency improvement that produces economic benefits independent of environmental ones. It is also important to recognize that all of society benefits when a country faces fewer costly health and environmental problems, especially future cleanups of contaminated land and water.

After more than a decade of effort, most large companies in developed countries have undertaken formal waste reduction or pollution prevention programs. Also, in some countries, government programs emphasize pollution prevention by, for example, providing free technical assistance for smaller companies. International groups such as the United Nations Environment Program and foreign assistance programs such as those administered by the U.S. Agency for International Development are providing increased waste reduction assistance to developing countries. The message is that economic growth does not have to result in massive, unmanageable amounts of waste.

Waste reduction has also stimulated market demand by companies and individual consumers for environmentally preferred or environmentally friendly products and technologies, for which different types of pollution prevention methods are used. Whole new industries are being created by the global environmental marketplace for "green" products. For example, hazardous chemical solvents used widely in industry and elsewhere for cleaning are being replaced by water-based, nontoxic alternatives that can be disposed of easily and safely.

With the wider recognition of the waste hierarchy, questions have arisen regarding what actions are needed to reduce or prevent waste. There are three basic levels of prevention that can be used singly or in combination:

- Changing the raw materials used to make things or perform services;
- Changing process technologies in manufacturing and other sectors, such as energy, transportation, agriculture, and mining; and
- Redesigning, reformulating, and repackaging products.

If one knows waste composition or what is hazardous about a waste, it becomes clear that using different materials may reduce waste quantities and that substituting nontoxic for toxic raw materials can transform a hazardous waste into a solid waste. For example, the use of some plastics for packaging common consumer products has reduced the weight of post-consumer waste compared to paper or glass packaging discards. But plastics are not as easily recycled as paper or glass.

For hazardous waste, a reduction in the use of toxics can substantially reduce hazardous waste quantities. One example is eliminating mercury from common types of batteries, which has reduced hazardous waste from manufacturing and helped resolve a problem in municipal solid waste. But it takes new technology to accomplish such changes, and not all companies are willing to change successful products.

Another important example of reduction in the use of toxics is the widespread replacement of chlorinated solvents in paints and inks with water or other safe materials. Lead has been eliminated from many manufacturing operations, such as soldering seams in food cans. The pulp and paper-making industry is gradually reducing or eliminating its use of chlorine. Changing fuels also fits this category, including the use of low-sulfur coals or natural gas for power plants producing electricity, which reduces solid waste generation from air pollution control equipment.

A great deal of effort has been given to changing the technologies, practices, and procedures within manufacturing operations to make them more efficient. As a result, this second level of pollution prevention has enormous promise. Increasing efficiency means using less raw materials — including chemicals, metals, fuels, and water — to make products. Similar actions can

CHINA'S CLEAN TECHNOLOGY PROJECT

With so many countries undergoing rapid industrialization, there is a unique opportunity to incorporate pollution prevention technology in new industrial infrastructures. But it is difficult to create an effective pollution prevention ethic throughout society. The solution is to recognize the importance of using a national pollution prevention strategy and creating a new policy and industrial framework to implement it.

With World Bank and United Nations assistance, this approach is under way in China, which has explicitly emphasized the benefits of using clean technology within a national economic development framework.

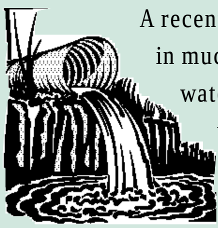
Various data show the need for waste reduction on both economic and environmental grounds. For example, the government has noted that China consumes 10 to 100 times more water than industrialized countries to produce a ton of industrial product, and thus recognizes the economic advantages of waste reduction. Given the rapid rate of industrial expansion in China, it is clear that huge volumes of waste would soon slow down the desired economic growth.

A comprehensive approach is being used to address all levels of pollution prevention. Substantial training programs are being used, and there are technology demonstration projects in such industries as chemicals, pharmaceuticals, brewing, petrochemicals, and electroplating. One goal is to have 100 of the 3,000 companies accounting for 65 percent of China's waste and pollutant generation using cleaner production methods within five years of the start of the project.

3M POLLUTION PREVENTION PROGRAM

A large multinational company producing over 60,000 different products, 3M has been one of the industrial pioneers in waste reduction. What is unusual about 3M was its early perception that increasing interest in environmentalism would lead to escalating waste disposal or treatment costs. Essentially, the company asked itself what the best economic strategy would be. The answer was a corporate “Pollution Prevention Pays” program started in 1975, about 10 years ahead of nearly all other large industrial companies.

In the past 20 years, 3M has undertaken more than 2,500 projects in Argentina, Australia, Belgium, Brazil, Britain, Canada, France, Germany, Italy, Japan, Mexico, New Zealand, the Philippines, South Africa, Spain, Sweden, Switzerland, Thailand, the United States, and Venezuela, thus spreading the pollution prevention philosophy worldwide.



A recent success shows how water, an increasingly scarce resource in much of the world, can be conserved. At a U.S. plant, cooling water that previously had been collected for disposal with wastewater is now reused. By building a water recycling facility at a cost of $480,000, 3M reduced the size of a planned wastewater treatment facility, which would have produced more solid waste, and saved $800,000 on the construction cost alone.

Overall, 3M has saved more than $500 million worldwide, and it has reduced solid wastes by over 400,000 tons. Most importantly, it has shown other firms that large amounts of waste reduction and pollution prevention can be accomplished in the near term, and that it makes a company more profitable as well as socially responsible.

be taken in other sectors, such as agriculture, mining, and energy production.

Conceptually, waste reduction means converting less purchased materials to solid or hazardous waste, achieving a higher level of process efficiency and materials utilization. Often, no-cost or low-cost changes can be made in existing industrial facilities, including recycling within process operations, and these pay for themselves in short order.

For example, there have been dramatic changes in how industrial equipment is cleaned. Huge amounts of water once were used, which created large volumes of slightly contaminated wastewater. Newer techniques use very little water or improved dry cleaning methods. In many companies, simply separating different kinds of waste has resulted in a smaller quantity defined by law as hazardous, and it has made it easier to recycle or reuse some materials, either onsite or offsite. Recovering metals from water in manufacturing and reusing both the metals and the water is also considered source reduction. But in many cases, companies also need to change the fundamental process technologies in order to obtain major waste reductions. However, this can require large capital investments and can pose implementation problems. Such advanced forms of waste reduction generally require strong management support and clear government policies and incentives.

The third level of pollution prevention is changing something about a product — including its composition, its design, its packaging — to reduce waste generation during manufacture and after the product is used. There is now a very active “green” market, and environmentally preferred products have flooded the marketplace in the United States and some European countries.

Using recycled materials and recyclable or compostable materials has become a main feature of green products. Consumer products with less packaging, no toxic chemicals, and often smaller sizes (because liquids have been concentrated) have also become commonplace. For example, many laundry detergents now come in much smaller plastic containers than previously used, and the containers are made from recycled plastic. Coffee makers and detergent companies have stopped placing plastic measuring spoons in their products because, most of the time, they became immediate waste. Many consumer health care products are now simply wrapped, without being placed in a carton that really is unnecessary. Such actions reduce solid waste generation without sacrificing product quality and cost.

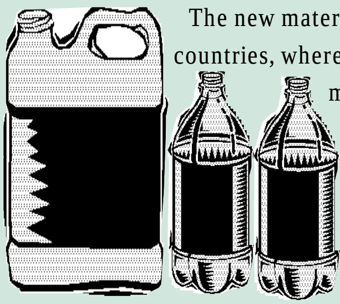
Because of the rapid growth of green product design and marketing and the related growth in making environmental claims for products, government controls have become necessary to address misleading and fraudulent claims. In the United States, green product claims used in product labels, packaging, or advertisements have come under considerable state and federal scrutiny and regulation, forcing some companies to change these claims.

Several countries — including Canada, Germany, and Japan — have national product evaluation and labeling programs to certify green products. In the United States, two

BIOPOLYMERS

Plastics have long been associated with negative environmental impacts, but an important new materials revolution could change this. It is the replacement of conventional low-cost, petroleum-base plastics with agricultural-derived materials made from crops such as corn or potatoes, or from food processing solid waste.

The new “biopolymers” generally can be manufactured using equipment currently used to make such plastic products as disposable food service utensils and bags, and to have similar physical and mechanical properties. However, unlike so-called degradable plastics, which have been strongly condemned by environmentalists because they are not biodegradable, the biopolymers can be made to be fully biodegradable and compostable under various conditions.



The new materials are very attractive both for industrialized countries, where replacing plastics with biopolymers will make more waste amenable to composting, and for developing countries, where littering and open dumping has caused a glut of plastic waste. If plastics were replaced with biopolymers in those developing countries where municipal waste has a very high organic content, wide-scale composting could solve a number of problems.

Several major U.S. companies have invested millions of dollars in developing and commercializing these new materials, which will also reduce the use of petroleum and chemical industry facilities — the source of considerable toxic waste. In other words, biopolymers have life-cycle environmental advantages — from raw materials through manufacture and eventual post-product disposal — relative to the plastics and paper products they replace. Using discarded biopolymers to produce soil amendments through composting also promotes sustainable agriculture techniques. Also, the biopolymers could essentially eliminate the problems of plastic litter on land and in oceans.

Already there are several products made from biopolymers, including: loose-fill packing “peanuts” that formerly were made from polystyrene but now are immediately broken down by water into tiny particles that will biodegrade; golf tees that quickly degrade upon watering and reduce problems for grass cutting equipment; and bags to collect compost that are transparent to allow detection of noncompostable materials, are fully biodegradable so that they do not have to be unpacked, and are stronger than paper bags.

private sector organizations certify products, but these have not yet been widely used by companies. Also, various U.S. government agencies have issued definitions of acceptable practices for industry use in product claims to help police the green market.

But in other countries, and especially in their large cities, green products are not widely available. In expanding urban places, rapid increases in population and consumption of Western-style consumer products are resulting in enormous increases in municipal solid waste. Existing government systems often are ill equipped to manage wastes effectively. Thus, plastic trash and empty packages can be seen nearly everywhere.

While countless success stories validate the promise of waste reduction, the total impact on waste generation worldwide is still unclear. In the United States and other developed countries, traditional pollution control and waste management options lower on the hierarchy are highly regulated and mandated but are not outlawed. Waste reduction is mostly voluntary, and it is stimulated through a host of economic and social incentives that can take time to develop. The question is: Can the world rely on voluntary pollution prevention to remove all the threats from solid and hazardous waste?

The United States has a federal pollution prevention program, as well as similar programs in almost all of the 50 states. These government programs provide technical assistance, public awards and recognition, technology transfer, and often loans and subsidies for hazardous waste reduction activities. While some other countries have similar efforts, the United States is the only nation that requires industry to make detailed data on waste generation publicly available — in what is known as the Toxics Release Inventory — as well as waste reduction actions and plans.

This public display of data has stimulated considerable industrial waste reduction because of industry reaction to adverse publicity about specific wastes and pollutants. Such green market forces are increasingly effective in stimulating U.S. waste reduction, especially for hazardous waste. But they depend on having an informed public and effective nongovernmental environmental organizations to analyze and disseminate the data.

RECYCLING

Recycling can take several forms:

- Reusing materials that otherwise would be discarded after their original application — for example, reusing glass beverage bottles and the steel drums used for chemical shipments;
- Recovering materials in, for example, a central facility that takes industrial furnace slags or collected dusts to recover a valuable metal, or a de-inking plant that takes newspaper to make pulp recycled paper; and
- Recycling a material for a different application through some type of processing or manufacture, including turning mixed plastics into park benches, organic wastes into compost, and glass waste into construction or road material.

The order of these activities is not accidental. It reflects favoring the highest value form of recycling in terms of low cost and minimum industrial processing, which itself produces waste and pollution. Higher value also refers to reducing the use of virgin materials for applications because products are reused or recycled material is used. Reducing virgin material conserves natural resources, as well as minimizing pollution problems in industries that convert raw materials into finished products. To some extent, therefore, an issue arises because large industries based on virgin materials become threatened when their customers switch to recycled materials.

Notable examples of high-value recycling include paper that has a very high recycled-paper content or is made entirely of recycled material, steel and aluminum made entirely from scrap materials, and automobile oil made from reprocessed oils. The competition between large paper mills using virgin trees and recycling facilities using post-consumer discarded material has sometimes slowed the shift to greater use of recycled material. Often, the price of paper products made from recycled material is higher than for products based on virgin materials because the older, larger facilities that work with virgin materials have a competitive advantage over more expensive, newer, and smaller-scale plants converting recycled materials. Also, consumers who profess to want green products often are faced with choices regarding both price and some aspect of product appearance or quality when considering recycled materials.

Lower-value types of recycling,

RECOVERY AND RECYCLING OF CHROMIUM IN A TANNERY

All over the world there are small leather tanneries, many of them in developing countries. One reason that tanneries have shifted from developed to developing countries is that they pose environmental problems. Although end-of-the-pipe solutions to these problems have been known for years, they add considerably to the cost of running tanneries. Hence, tanneries in developing countries without stringent regulatory requirements could be especially competitive. But as developing countries start to be more environmentally concerned, this advantage is diminished.

More interestingly, tanneries in developing countries also have an opportunity not to use the standard pollution control measures but to use a waste reduction approach that actually reduces operating costs while eliminating the environmental problem. For example, a project conducted from 1988 to 1990 investigated how trivalent chromium used as the major tanning agent — and the major environmental culprit — could be better managed through recovery and reuse.

A tannery near Athens, founded in 1978, produces 2,200 tons annually of high-quality leather from cattle hides, has a staff of 65, and has annual revenues of over $8 million — making it typical of tanneries in many other countries. The environmental issue is that untreated chromium-contaminated wastewater constitutes an industrial hazardous waste, and that use of water treatment pollution control produces hazardous sludge. In conventional chrome tanning worldwide, about 20 percent to 40 percent of the chrome purchased is discharged in the wastewater.

With new technology, 95 percent to 98 percent of the waste chrome can be recovered and recycled within a plant. This is accomplished by filtering and pumping the liquids that exist after hides are soaked in a chromium sulphate solution to a treatment tank where magnesium oxide is added to achieve a certain level of alkalinity. This causes precipitation of chromium hydroxide as a sludge. After settling, the clear water is decanted off and the remaining sludge is dissolved in concentrated sulfuric acid until a specified level of acidity is reached. This new liquid is then available for reuse as the tanning solution, and relatively clean wastewater has been discharged.

This technology can be used in every conventional chrome tanning operation. It reduces the amount of chemicals that must be purchased, making tanneries not only environmentally sound but more profitable, because chemical costs are a very large fraction of total operating costs.

material.

Composting of solid waste deserves special attention even though it is a lower-value form of recycling. Most municipal solid waste contains a high fraction of organic, biodegradable material, such as food waste, lawn clippings, yard waste, and wet and soiled paper unsuitable for recycling. In industrialized countries, easily 50 percent of household waste is organic material; for restaurants, it can be as high as 75 percent. Residential waste in developing countries is very high in food waste, often well over 50 percent, because less processed and packaged food products are used.

Composting uses controlled or engineered biodegradation, typically over some weeks or months, to recycle organic materials into a soil amendment. The agricultural and horticultural use of compost improves soil quality, reduces irrigation needs, and cuts both soil erosion and the use of chemical fertilizers, which is consistent with sustainable agriculture.

The composting of solid waste is especially attractive in places where the use of landfills or incinerators is very expensive, as it is in much of the United States and Europe, and where natural soils are of low quality, such as in the arid countries of the Middle East.

Market forces of supply and demand have always played a crucial role in determining the level of recycling in any location. In all societies, recycling has been practiced to the degree that separable materials could be profitably collected and sold, either by individuals or companies. In some countries, the poor survive by sorting garbage and selling materials for reuse or recycling. However, as solid waste quantities in urban areas increase, such small-scale recycling can become difficult, dangerous, and insufficient. In

COMPOSTING OF MUNICIPAL SOLID WASTE IN MINNESOTA

Although most public attention has been directed toward the recycling of materials such as paper and metals, to reduce dependence on land disposal and incineration, composting is undergoing rapid growth in the United States. One of the great uncertainties facing composting, however, is whether it is feasible and cost-effective to collect organic waste for composting.

For several years, two counties (Fillmore and Swift) in the northern U.S. state of Minnesota have employed a waste collection system for households that requires separation of compostable materials, such as food waste and soiled and wet paper, usually in paper or plastic bags. Nearly all households participate, which has resulted in about 50 percent of municipal solid waste being collected for composting, resulting in a total of 65 percent to 75 percent of MSW being recycled and composted, and thus diverted from disposal.

These and other demonstration programs are showing that the public policy goal of minimizing land disposal can be accomplished by a combination of composting and recycling, but not by recycling alone. Without composting, most U.S. cities can divert only about 20 percent to 30 percent of MSW through recycling programs.

A study that examined the potential demand for compost found that, if all the organic waste in the United States was composted, it would meet about 10 percent of the potential demand, mostly in agriculture, where soil erosion and contamination by chemical fertilizers are greatly reduced by using compost. An examination of the potential economic benefits of maximizing the use of composting in the United States found that $1 thousand-million to $2 thousand-million could be saved annually by shifting organic waste from landfills and incinerators to composting.

involving substantial industrial processing, are an issue because many of today's waste cleanup sites were formerly recycling facilities that contaminated land and water, such as facilities that processed lead batteries from automobiles and products with mercury. The solution is to impose stringent regulations on such recycling facilities, comparable to those for primary manufacturing facilities.

The reuse category also includes public and private waste exchanges through which industrial firms can send nonproduct outputs that can be used by other firms and reduce their purchases of virgin materials. Waste exchanges operated by government agencies or private groups cover many chemicals that otherwise would become hazardous waste. Even if a company does not receive payment for a material, it generally can avoid enough waste management costs to make the effort profitable. But in general, there is little recycling of hazardous waste and much more of solid waste.

A problem with the waste exchange concept is that relatively small amounts of chemicals with slightly varying amounts of impurities are obtained at irregular intervals. This creates problems for users trying to replace standardized types of virgin chemicals that must meet stringent specifications. One solution is to use some discarded materials for their heating value in certain types of furnaces, such as cement kilns. Another is to mix a small amount of recycled material into a much larger amount of virgin industrialized countries, successful private sector recycling companies have always existed. However, such firms can be too efficient in collecting large amounts of material; this creates an excess supply that, in turn, lowers prices and makes many recycling efforts economically inefficient. The result is a supply-demand mismatch that causes a shift downward on the waste hierarchy to more land disposal.

The supply-demand problem is more than just a local problem; it has become a global market issue for some recycled materials because of exports. Paper and ferrous materials are often exported from the United States to Asian markets, for example. However, such exports do not result in less virgin material being used in the United States. Environmentalists say that such exporting is exporting more than recyclable material; it is exporting threats to public health and the environment. The solution then is balancing supply and demand at the local level.

Paper and plastics pose especially difficult problems in matching supply with demand. For paper the problem is displacing existing mills and systems using virgin trees and pulp, while plastics are very costly to collect and transport. Plastics also pose tough technical problems because many kinds of plastics are difficult to use together for high-value applications, and separation is costly. Also, there is limited demand for low-value products such as plastic lumber and similar items for which mixed plastics can be processed and used.

An issue that exists at the interface between recycling and treatment is burning waste for energy recovery. Most large-scale solid waste incinerators and some hazardous waste units recover heat that generates electricity. In the United States, the prevailing perspective is that this activity is not recycling. However, in Europe the opposite is generally the case. Many environmentalists believe that incinerating waste produces too much air pollution and solid waste residue (or ash) to be considered environmentally acceptable.

Often, for example, the ash left from municipal solid waste incinerators after burning is itself a hazardous waste because of high leachable metal content, such as mercury, cadmium, and lead. The incineration of hazardous waste is also opposed because of the potential for toxic air releases, whether the burning is done in hazardous waste incinerators or industrial boilers, furnaces, and cement kilns, even though less fuel is used because waste is burned.

Advocates of waste incineration as energy recovery believe it is better than disposing of waste on land. Incineration opponents believe that recycling and composting are preferred alternatives for solid waste, and source reduction and various treatment technologies other than incineration are preferred for hazardous waste.

The future for recycling of municipal solid waste is positive as supply-demand problems are solved. Vigorous government-supported recycling programs should allow recycling and composting to reach levels of about 75 percent or more eventually. This would leave about 10 percent for incineration and 15 percent for landfilling. But it may take a decade or more to reach these levels for the industrialized world, and much longer for the rest of the planet. In the meantime, most solid waste will be land disposed; most hazardous waste will undergo treatment in industrialized countries and land disposal in developing ones.

WASTE TREATMENT

The treatment component of the waste hierarchy aims to convert waste into something that is environmentally harmless, has a reduced volume, and perhaps produces a residue with some economic value. Waste treatment technologies generally fit into the following broad categories: thermal, biological, chemical, physical, or some combination of these.

A generic problem with waste treatment is its high cost relative to land disposal options. Another problem is the pollution caused by treatment methods, which has contributed to higher costs because of government regulations that require the use of complex equipment to render the treatment facilities environmentally acceptable.

As discussed earlier, the main thermal method is incineration, in which waste is burned to convert combustible materials into gases, leaving a solid residue of ceramic and metallic materials. Other forms of thermal treatment may use different types of furnaces and methods of heating. Cement kilns that operate at high temperatures are used for burning hazardous waste in some countries. They face a relatively high level of government regulation, however. Other high-technology forms of thermal treatment include plasma and thermal desorption furnaces for destroying hazardous waste, and methods that convert solid waste into petroleum-like liquid or into ceramic aggregate or particulate material for construction uses.

Generally, the use of thermal methods is limited by their high cost and by environmental concerns about air pollution and residue management, which can cause passionate public opposition to siting new facilities. In fact, in the past few years, a number of

CEMENT KILNS FOR HAZARDOUS WASTE BURNING

As U.S. regulations made the use of land disposal of hazardous waste costlier and riskier because of legal liabilities for future cleanup, waste generators started using more incineration. But the cost was very high, often thousands of dollars for a ton of waste compared to a few hundred for disposal in landfills. Also, the U.S. Environmental Protection Agency requires incineration for many kinds of hazardous waste. So although high incineration costs are an economic incentive for waste reduction, many companies still require incineration. Some use incinerators on their industrial sites; others use expensive commercial hazardous waste incinerators.

The rotary kilns used to incinerate most hazardous waste are essentially the same as the rotary kilns used for decades to make cement. Cement kilns require substantial fuel, and cement manufacturers could substitute certain hazardous wastes with high heating value for expensive fossil fuels. By doing so, cement companies could reduce their fuel costs, and waste generators could reduce their disposal costs.

The EPA's regulatory requirements for incineration could be met by about one-fourth of the 100 portland cement kilns in the United States. In 1991, cement kilns burned 1.3 million tons of hazardous-waste-derived fuels in the country. The usual types of hazardous waste that are blended and burned in cement kilns are: industrial cleaning solvents, printing inks, paint thinners and residues, waste oils, and various high-heat-content organic wastes. Cement kilns are seen as a form of recycling and fossil fuel substitution by their advocates, although environmentalists believe that current government regulations do not effectively prevent toxic air releases from any form of incineration.

For different reasons, cement kilns offer promise for developing countries. If the likely alternative is open dumping or unsafe landfills, and if serious industrial waste reduction is not immediately likely, then cement kilns may be the best solution for some especially toxic industrial wastes. For example, in several places in North Africa, there are large amounts of waste pesticide materials, and cement kilns could be the solution.

planned U.S. and European projects to build new hazardous waste incinerators have been cancelled. Although economics may explain some drop in demand, most professionals cite waste reduction as the primary reason. Moreover, many existing municipal solid waste incinerators in the United States designed for high rates of waste burning are now struggling because of the diversion of wastes to recycling, composting, and even low-cost land disposal. Overall, the future for waste incineration is not promising. The high cost and technical complexity of incineration units with extensive pollution control systems also pose problems for use in developing countries, where such capital investments can be quite risky.

There is continuing interest in using biological methods to treat both solid and hazardous waste, but there are significant limitations. Various types of microbiological organisms can consume and convert some organic materials into harmless and even usable by-products, such as methane gas. Some municipal solid waste and sludge from wastewater treatment plants are being treated in engineered vessels in which anaerobic (non-oxygen) biodegradation takes place relatively quickly and produces usable methane gas. However, the future use of biological methods for solid and hazardous waste is likely to be limited because of long treatment times, high equipment costs, and an effectiveness that is chemical specific, making treatment of complicated waste streams difficult.

Chemical methods cover many different techniques used for hazardous waste treatment, including chemical fixation or stabilization, by which waste is blended with carefully controlled liquids and ceramic-type material to produce cement-like material from which toxic chemicals should not escape. Such methods are relatively low cost but lead to higher-volume materials that must be disposed of in landfills. Another category is chemical treatment that breaks down certain types of toxic organic molecules into simpler, harmless materials to be disposed of. There are also techniques that use different types of radiation, such as ultraviolet, to destroy organic molecules in liquid hazardous waste.

In spite of the large number of chemical technologies developed for hazardous waste treatment, such methods have limited use because of high equipment and operating costs, technical complexity, limited histories of proven commercial use, residues that require costly management, and a market in which industrial wastes change rapidly as production methods and products change. Added to these is uncertain government regulation of innovative new technologies and the residues they produce.

Physical treatment of waste may involve simple dewatering of solids and sludges to lower subsequent waste management costs and problems, simple separation of oily components of some wastewaters, or filtering of solids from liquid waste. Water, oils, or even metal particles that are separated often can be reused. New filtering approaches are allowing motor and machine lubricating fluids to be used for very long times. Most physical treatments are relatively low cost, but often they are not the only treatment that must be used for complete waste management.

LAND DISPOSAL

In spite of all the attention to waste reduction, recycling, and treatment, the dominant form of solid and hazardous waste management worldwide remains land disposal. Even though the threats to groundwater, surface water, and soil are well known, the presence of low-cost, available land generally leads to the wide use of land disposal.

In industrialized countries, the problems of land disposal have been addressed largely by imposing stringent regulations designed to make the practice safer rather than outlawing it altogether. These regulations have also raised the cost of land disposal enormously.

Still, most environmentalists believe that all control technologies will ultimately fail, and basic principles of chemistry and physics support that view. There is an eventual physical or chemical deterioration of critical containment components, and there is a fundamental uncertainty about the ultimate fate of hazardous chemicals.

Regulations governing U.S. landfills require such measures as: multiple synthetic and impermeable liners and caps to limit water getting in and out; daily covering of waste with soil or other inert material; systems for collecting any water or leachate beneath the landfill and pumping it to the surface for analysis and, if necessary, treatment; and groundwater monitoring wells around a site to detect any leakage of toxic chemicals. There are also stringent standards that limit where landfills may be built, especially avoiding areas above groundwater serving as drinking water and other sensitive ecological assets. Many municipal solid waste landfills also have systems for extracting and using methane gas, which tends to form from the slow biodegradation of organic waste and which, historically, has caused fires and explosions.

Moreover, there are typically restrictions about what wastes can be placed in particular land disposal units. For example, U.S. hazardous waste landfills cannot accept liquid materials, and most hazardous wastes have to undergo some type of treatment, with only residues permitted for land disposal. However, most industrial solid wastes and municipal solid wastes are still landfilled, and liquid industrial solid wastes can be placed in surface impoundments or lagoons, allowing vaporization and settling to occur. Of course, increases in government regulation create an incentive to avoid high disposal costs. Illegal dumping of waste, noncompliance with regulations, and shipment to foreign countries are often practiced, rather than moving up the waste hierarchy to preferred solutions.

In some developing countries, open dumping of solid and hazardous waste without any controls clearly poses a much greater problem than modern, well-regulated land disposal facilities. Open dumps are not only sources of air and water pollution, but they are breeding grounds for vermin and contribute to public health problems. An issue for developing countries is that almost any type of engineered land disposal seems so much better than open dumping that movement up the hierarchy to waste reduction can be impeded; well-meaning government investments in well-designed landfills can turn out to be a disincentive for waste reduction.

Open dumping, therefore, remains a critical environmental issue for much of the world. In many places, expanding urbanization has claimed land that was previously used for open dumping of toxic wastes, creating the potential for increased human exposure to contaminated soil and groundwater. In some countries, open dumping and raw waste discharges into water (especially oceans) are also posing threats to tourism, which is an increasingly vital component of economic development.

In industrialized countries, the use of landfills for hazardous waste disposal has declined, as have, to a lesser extent, surface impoundments and deep injection wells for liquid wastes. However, a perverse effect of greater waste reduction and recycling has been a reduction in the use of landfills that has extended their lifetimes. Once again, the promise of waste reduction may be compromised.

One approach to solving these problems involves large, deep, natural salt domes. These are literally underground mountains of solid salt in which cavities are created hundreds or thousands of meters below ground level for disposal of treated hazardous waste. The argument favoring salt domes is that enormous amounts of natural salt provide a reliable long-term containment barrier for waste. Costs are higher than for landfills and injection wells but much lower than for incineration and other treatment methods. However, there are only limited locations that have the necessary high-quality salt domes, and the public seems as concerned about this type of facility as it is about landfills and incinerators.

CONCLUSIONS

There are two inescapable conclusions about global trends for solid and hazardous waste. First, waste quantities will continue to escalate sharply unless and until waste reduction efforts advance more rapidly than waste generation. Second, except for hazardous waste and, to a lesser extent, municipal solid waste in industrialized countries, most solid and hazardous waste will continue to be disposed of on land. Taken together, therefore, pollution threats to air, land, and groundwater from waste will increase for much of the world's population.

The two major challenges for national governments and international institutions are to improve the quality of land disposal and waste treatment in developing countries, and, simultaneously, to greatly increase support for solid and hazardous waste reduction methods.

However, the task of addressing solid and hazardous waste problems suffers from several comparative disadvantages. Waste problems tend to be local in nature and therefore are often seen as less important than global or transnational environmental problems. Waste problems also may seem less important than severe air pollution and polluted drinking water, which directly affect large populations and are addressed through conventional pollution control technologies.

Moreover, solid and hazardous waste issues are closely tied to the dominant style of consumer demands, economic development, industrialization, and urban living, which intrinsically create high rates of waste generation. The generally emulated materials-intensive and consumptive-style of Western culture has caused a global demand for a waste-intensive style of economic progress. Indeed, to some, greater waste is proof that economic development is occurring.

In light of these conditions and trends, policy-makers are giving increasing attention to using market forces and economic incentives to address solid and hazardous waste problems, especially through waste reduction and recycling. The basic message is that reduction and recycling are not the enemy of economic growth; rather, they promote sustainable economic development. Regulatory approaches to control incredibly large numbers of waste sources and management facilities require extensive resources to design, implement, and enforce. They can be especially costly and difficult for developing countries, and, because heavy regulation of waste means high disposal costs, they meet with resistance from the private sector everywhere.

Nevertheless, it remains necessary to have regulations and standards that create the proper setting to stimulate waste reduction, recycling, waste treatment, and engineered forms of land disposal — in that order. It is the dependence on regulations that must decrease. But a regulatory structure should be available to use when necessary to guide decisions about technology and waste management. However, waste generation is so intimately connected to the fabric of human society that nonregulatory approaches to stimulate adherence to the waste hierarchy, with a preference for waste reduction and recycling, are also imperative.

If regulations and the threat of tough penalties for violators of regulations are the proverbial stick to force people to do the right things, then nonregulatory measures are the carrots to attract, help, and reward people for using preferred approaches. There are many such nonregulatory approaches, including the following:

- Adoption of a national policy that recognizes the waste hierarchy and that pledges support for its implementation;
- Education in primary schools through university programs for engineers and managers about waste issues and the need for pollution prevention;
- Government policies that reduce subsidies for materials, water, and fuels to increase the economic benefits of waste reduction;
- Government-supported technical assistance programs for private sector firms, especially smaller ones, and provision of technical information for specific sectors;
- Government assistance for funding of capital improvement projects that implement pollution prevention or clean technologies in new or existing plants;
- Government- and industry-supported award programs to recognize truly green technologies, products, and industrial facilities;
- National laws that require public disclosure of waste generation by private and public entities;
- Government support for environmental nongovernmental organizations to stimulate and sustain wide public support for progressive waste policies and programs;
- Government taxes on waste generation and fees for municipal solid waste collection and management on a weight or volume basis, to encourage waste reduction and recycling;
- Import taxes on waste-intensive products that result in excessive solid waste generation;
- Legal requirements to use post-

consumer recycled materials in products and packaging to stimulate demand for recycled materials;

- Government-supported use of international information and technology transfer programs and electronic databases, such as the United Nations' Cleaner Production Program and the U.S. Agency for International Development's Environmental Pollution Prevention Program. ❏

GLOSSARY

Biodegradable: The capacity of a material to be decomposed by micro-organisms (fungi and bacteria) and macro-organisms (snails, slugs, etc.) under conditions that have relevance for waste disposal and management.

Composting: A controlled process of organic breakdown of biodegradable matter, usually in air and under sufficiently wet conditions; the usable product of this process is compost or humus that is valuable as a soil amendment or conditioner.

Environment: All external influences and conditions affecting the life and development of an individual and a community, including air, water, and land, and the interrelationships of these with all living things.

Hazardous waste: Any solid or liquid discarded material that is legally defined to be sufficiently dangerous to human health or the environment to justify special government-regulated handling, transport, and management (also toxic waste).

Landfill: A waste disposal facility in or on land into which waste is placed or buried; if engineered and using various forms of water and chemical containment technologies, it is a sanitary or secure landfill.

Leachate: Any liquid, including any suspended components in liquid, that has percolated through or drained from solid or hazardous waste, usually in a landfill or open dump.

Open dump: A site where solid or hazardous waste is indiscriminately disposed of without the use of engineered design and controls to provide hygienic and safe conditions.

Pollution prevention: Any technique, method, or technology that reduces or eliminates the original generation of a nonproduct waste output or the use of toxic or hazardous raw material. (Also, source reduction, toxic use reduction, waste reduction, waste minimization, clean technology, cleaner production, green product or technology.)

Solid waste: Any garbage, refuse, trash, rubbish, or sludge discards or byproducts resulting from industrial, commercial, residential, community, mining, energy production, and agricultural activities, and residues from pollution control equipment, in solid, liquid, semisolid, or contained gaseous forms.

BIBLIOGRAPHY

Batstone, Roger et al., eds. *The Safe Disposal of Hazardous Wastes — The Special Needs and Problems of Developing Countries.* Washington, D.C.: The World Bank, 1989.

Blumberg, Louis and Robert Gottlieb. *War On Waste — Can America Win Its Battle With Garbage?* Washington, D.C.: Island Press, 1989.

Center for Investigative Reporting. *Global Dumping Ground — The International Traffic in Hazardous Waste*, Washington, D.C.: Seven Locks Press, 1990.

Characterization of Municipal Solid Waste in the United States: 1992 Update. Washington, D.C.: U.S. Environmental Protection Agency, 1992.

Cleaner Production Worldwide. Paris: Industry and Environment Office, United Nations Environment Program, 1993.

Denison, Richard A. and John Ruston. *Recycling and Incineration — Evaluating the Choices*. Washington, D.C.: Island Press, 1990.

Freeman, Harry M., ed. *Standard Handbook of Hazardous Waste Treatment and Disposal.* New York: McGraw-Hill, 1989.

Heaton, George et al. *Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century*. Washington, D.C.: World Resources Institute, 1991.

Hirschhorn, Joel S. and Kirsten U. Oldenburg. *Prosperity Without Pollution — The Prevention Strategy for Industry and Consumers*. New York: Van Nostrand Reinhold, 1991.

Hirschhorn, Joel S. *Pollution Prevention Implementation in Developing Countries*. Durham, N.C.: Duke University Center for Tropical Conservation, 1993.

Jackson, Tim, ed. *Clean Production Strategies*. Boca Raton, Fla.: Lewis/CRC Press, 1993.

Maltezou, Sonia P. et al., eds. *Hazardous Waste Management*. London: Tycooly, 1989.

Methods To Manage and Control Plastic Wastes. Washington, D.C.: U.S. Environmental Protection Agency, 1990.

Murarka, Ishwar P. *Solid Waste Disposal and Reuse in the United States*. Boca Raton, Fla.: Lewis/CRC Press, 1987.

Platt, Brenda A. et al. *Garbage in Europe: Technologies, Economics, and Trends*. Washington, D.C.: Institute for Local Self-Reliance, 1988.

Platt, Brenda A. et al. *Beyond 40 Percent — Record-Setting Recycling and Composting Programs.* Washington, D.C.: Island Press, 1991.

Office of Technology Assessment. *Managing Industrial Solid Wastes*. Washington, D.C.: U.S. Government Printing Office, 1992.

Office of Technology Assessment. *Serious Reduction of Hazardous Waste — For Pollution Prevention and Industrial Efficiency*. Washington, D.C.: U.S. Government Printing Office, 1986.

Sullivan, Thomas F.P., ed. *The Greening of American Business*. Rockville, Md.: Government Institutes, 1992.

Theodore, Louis and Young C. McGuinn. *Pollution Prevention*. New York: Van Nostrand Reinhold, 1992.

Wagner, Travis P. *Hazardous Waste — Identification and Classification Manual*. New York: Van Nostrand Reinhold, 1990.

World Wildlife Fund. *Getting at the Source — Strategies for Reducing Municipal Solid Waste*. Washington, D.C.: Island Press, 1991.

CONTACTS

American Institute for Pollution Prevention
1616 P Street, N.W.
Suite 100
Washington, D.C. 20036 U.S.A.
Phone: 202-792-6567

Center for Pollution Prevention
9 Forrest Street
Boston, Mass. 02140 U.S.A.
Phone: 617-576-3448

Center for the Biology of Natural Systems
Queens College, City University of New York
Flushing, N.Y. 11367 U.S.A.
Phone: 718-670-4180

Center for Clean Products and Clean Technologies
University of Tennessee
327 S. Stadium Hall
Knoxville, Tenn. 37996 U.S.A.
Phone: 615-974-4251
Fax: 615-974-1838

Center for Waste Reduction Technologies
American Institute of Chemical Engineers
345 East 47th Street
New York, N.Y. 10017 U.S.A.
Phone: 212-705-7407
Fax: 212-752-3294

Citizen's Clearinghouse for Hazardous Waste
P.O. Box 6806
Falls Church, Va. 22040 U.S.A.
Phone: 703-237-2249

Environmental Action Foundation
6930 Carroll Avenue
Takoma Park, Md. 20912 U.S.A.
Phone: 301-891-1100
Fax: 301-891-2218

Hazardous Waste Research and Information Center
Illinois Water Survey Division
1808 Woodfield Drive
Savoy, Ill. 61874 U.S.A.
Phone: 217-333-8940

Hazardous Waste Treatment Council
915 15th Street, N.W.
Washington, D.C. 20005 U.S.A.
Phone: 202-783-0870
Fax: 202-737-2038

INFORM, Inc.
381 Park Avenue
New York, N.Y. 10016 U.S.A.
Phone: 212-689-4040

Institute for Local Self-Reliance
2425 18th Street, N.W.
Washington, D.C. 20009 U.S.A.
Phone: 202-232-4108
Fax: 202-332-0463

International Association for Clean Technology
Wirtschaftsuniveristaet Wien
Augasse 2-6
A-1090 Vienna
Austria
Phone: 01-313-364577
Fax: 01-319-41-82

International Chamber of Commerce
Office of Environment and Energy
P.O. Box 301
N-1324 Lysaker
Norway
Phone: 47-2- 581-800
Fax: 47-2-581-875

3M Company
Pollution Prevention Programs
900 Bush Avenue
St. Paul, Minn. 55144 U.S.A.
Phone: 612-778-4805

Municipal Solid Waste Management Association
1620 I Street, N.W.
Washington, D.C. 20006 U.S.A.
Phone: 202-293-7330

National Recycling Coalition
1101 30th Street, N.W.
Washington, D.C. 20007 U.S.A.
Phone: 202-625-6406
Fax: 202-625-6409

National Roundtable of State Pollution Prevention Programs
P.O. Box 7219
Silver Spring, Md. 20910 U.S.A.
Phone: 301-495-9278
Fax: 301-589-7068

National Solid Wastes Management Association
1730 Rhode Island Avenue, N.W.
Washington, D.C. 20036 U.S.A.
Phone: 202-659-4613

Natural Resources Defense Council
40 West 20th Street
New York, N.Y. 10011 U.S.A.
Phone: 212-727-2700

North Carolina Office of Waste Reduction
P.O. Box 27687
Raleigh, N.C. 27611 U.S.A.
Phone: 919-571-4100
Fax: 919-571-4135

Organization for Economic Cooperation and Development
2 Rue Andre Pascal
75775 Paris Cedex 16
France
Phone: 33-1-45-24-9870
Fax: 33-1-45-24-7876

Solid Waste Association of North America
8750 Georgia Avenue
Silver Spring, Md. 20910 U.S.A.
Phone: 301-585-2898

United Nations Environment Program
Industry and Environment Office
39-43 Quai Andre Citroen
75739 Paris Cedex 15
France
Phone: 33-1-40-58-88-50
Fax: 33-1-40-58-88-74

U.S. Chamber of Commerce
1615 H Street, N.W.
Washington, D.C. 20062
Phone: 202-463-5533

U.S. Environmental Protection Agency
Office of Solid Waste
401 M Street, S.W.
Washington, D.C. 20460 U.S.A.
Phone: 202-260-4627

World Resources Institute
1709 New York Avenue, N.W.
Washington, D.C. 20006 U.S.A.
Phone: 202-638-6300

Joel S. Hirschhorn, who heads Hirschhorn & Associates in Wheaton, Maryland, is a recognized expert on pollution prevention and industrial waste reduction, clean manufacturing technologies and products, waste management technologies, and environmental management regulations and policy. He has conducted many studies for both government and private industry, nationally and internationally, helping to define key technology and environmental issues, policies, and solutions. Dr. Hirschhorn's numerous publications include Prosperity Without Pollution: The Prevention Strategy for Industry and Consumers.

GREEN PAPER SERIES

Editors: Rick Marshall, Kathleen E. Hug
Design: Thaddeus A. Miksinski, Jr.

UNITED STATES INFORMATION AGENCY
FEBRUARY 1996